Near infrared transillumination of the maxillary sinuses: overview of methods and preliminary clinical results

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ABSTRACT

Though sinusitis is a significant health problem, it remains a challenging diagnosis for many physicians mainly because of its vague, non-specific symptomology. As such, physicians must often rely on x-rays and CT, which are not only costly but also expose the patient to ionizing radiation. As an alternative to these methods of diagnosis, our laboratory constructed a near infrared (NIR) transillumination system to image the paranasal maxillary sinuses. In contrast to the more conventional form of transillumination, which uses visible light, NIR transillumination uses light with a longer wavelength which is less attenuated by soft tissues, allowing increased signal intensity and tissue penetration. Our NIR transillumination system is low-cost, consisting of a light source containing two series of light emitting diodes, which give off light at wavelengths of 810 nm and 850 nm, and a charge coupled device (CCD) camera sensitive to NIR light. The light source is simply placed in the patient's mouth and the resultant image created by the transmittance of NIR light is captured with the CCD camera via notebook PC. Using this NIR transillumination system, we imaged the paranasal maxillary sinuses of both healthy patients (n=5) and patients with sinus disease (n=12) and compared the resultant findings with conventional CT scans. We found that air and fluid/tissue-filled spaces can be reasonably distinguished by their differing NIR opacities. Based on these findings, we believe NIR transillumination of the paranasal sinuses may provide a simple, safe, and cost effective modality in the diagnosis and management of sinus disease.

INTRODUCTION

Sinusitis is a significant health care problem. In the United States alone, it affects approximately 31 million individuals and accounts for greater than $5.8 billion in direct and indirect health care costs annually[1]. Though physicians from many specialties (including otolaryngology, allergy/immunology, and infectious disease) play a role in the management of sinusitis, primary care physicians are called on to diagnose and treat 87% of cases[2].

Despite its prevalence, however, sinusitis remains a difficult diagnosis for primary care physicians to make. In an effort to help simplify clinical diagnosis, the American Academy of Otolaryngology-Head and Neck Surgery Task Force on Rhinosinusitis set forth a list of major and minor criteria that characterize the disease[3]. Nonetheless, there

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has never been a solid body of evidence to support the Task Force on Rhinosinusitis' symptom-based definition of sinusitis and, in fact, studies have found that the symptom-based definition overestimates disease[4]. The clinical diagnosis of sinusitis—especially when in its chronic form— presents many difficulties. For one, many of the symptoms associated with this disease are either vague or shared by other distinct etiologies (such as allergic rhinitis, vasomotor rhinitis, migraine, myofacial pain syndromes, temporomandibular joint disorders, and odontogenic problems). Moreover, clinical diagnosis depends on the patient's ability to convey a cogent history (which may be difficult when the patient is a child or speaks another language) and the clinical acumen of the doctor (which may be hindered by the limited consultation time in today's managed care environment). It is important, nonetheless, that sinusitis is properly diagnosed and treated because improper management can lead to further patient morbidity, antibiotic resistance, potentially serious complications, and additional health care expenditures.

Difficulties with the clinical diagnosis of sinusitis have led to an overuse of radiography. Unfortunately, the two most commonly used imaging modalities, plain film x-rays and computed tomography (CT) scans, involve the use of ionizing radiation, which is especially of concern when imaging children or pregnant women. Moreover, x-rays suffer from the superimposition of three dimensions onto two, leading to limited accuracy[5,6]. CT, though more accurate than plain film x-rays, is much more expensive and not as readily available[7].

As such, there is a need for a simple office-based objective study to help diagnose sinusitis without the cost and risk of traditional radiographical techniques. Historically, the office-based objective study used to diagnose sinusitis was transillumination. This technique involves the direct placement of an incandescent light source on a maxillary or frontal sinus wall to determine if there is fluid in the normally air-filled sinus. In sinusitis, fluid accumulates within a given sinus, resulting in increased absorption of light and decreased light transmission. Transillumination proved to be largely inaccurate, however, and was discarded at the earlier part of this century with the advent of radiography[8,9,10].

In this study, we improved upon the design of conventional transillumination by constructing a near infrared (NIR) transillumination system for the maxillary sinuses in which we replaced the traditional broadband light source with a NIR light source. Using a NIR light source allows for enhanced illumination of deep tissue structures and a stronger optical signal, because light in the NIR spectra (750 to 1100 nm) is poorly absorbed by water, the main constituent of biological tissues[11,12]. Because our eyes cannot detect light in the NIR spectra, we used a low-cost Charge Coupled Device (CCD) camera sensitive to NIR wavelengths to capture and record images.

Previous studies by Prapavat et al. described the technique of IR diaphonoscopy, correlated findings on IR transillumination with CT, and discussed it potential use in the management of sinus disease[13]. Nevertheless, these studies included only a few patients and, moreover, used multi-wavelength sources and detectors whereas our system is limited to lights of certain wavelengths selected for their optimal tissue penetration. This paper includes a description of our NIR transillumination system along with preliminary results from our ongoing clinical trial in which we compared findings on NIR transillumination of the maxillary sinuses with patients' CT scans.

MATERIALS AND METHODS

Our NIR transillumination system consists of two basic components: a NIR light source and a detector. The light source is designed to transpalatally illuminate the maxillary sinuses via the mouth (Figure 1). Structurally, the light source is in the shape of a spoon opposed to a flat base (with a handle at one end), as it was felt that this shape best conformed to the dimensions of the hard palate and mouth. The material chosen to construct the NIR light source, clear acrylic, has several properties which make it ideal for its purpose: it allows for the unimpeded transmission of NIR light and, moreover, is light-weight, non-toxic, durable, and sterilizable, making it suitable for repeated patient use. A rubber gasket is situated between the acrylic spoon and its opposing flat base to make the light source water-tight and, thus, isolate the electrical components from the patient. Actual transillumination is performed by two series of four light emitting diodes (Roithner Lasertechnik, Vienna, Austria) which are encased by the acrylic shell. One of these emits light with a wavelength of 810 nm and the other emits light with a wavelength of 850 nm. These specific light emitting diodes were chosen based upon previous experiments which revealed their optimal tissue penetration. In order to minimize the amount of light lost to scattering, copper tape is used as a reflective backing for the light source. Finally, the light emitting diode sockets are soldered onto wires and powered by a Hewlett Packard Power Source.

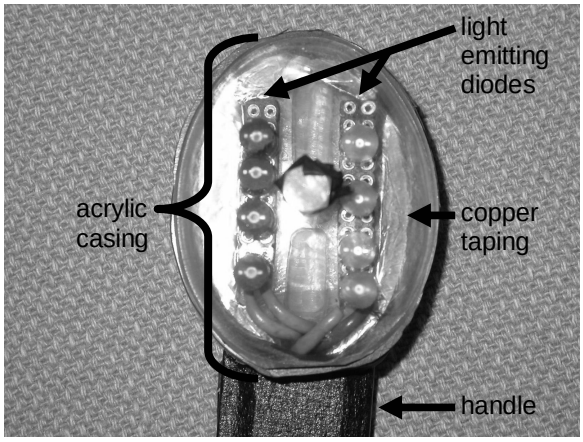

Figure 1. NIR transillumination light source.

Our detector consists of a silicon-based CCD video camera with peak spectral sensitivity in the NIR (Marlin P. Jones and Associates, Lake Park, Florida, USA). This camera, powered by a 5 volt power supply, is used to record NIR images of our subjects. The output from the camera interfaces with a USB port via a RCA to USB adapter, allowing patient data to be captured onto notebook PC using video capturing software (Pinnacle Linx Studio 7.0, Pinnacle Systems Inc., Mountain View, California, USA). The total cost of the NIR transillumination system, including the light source and detector, does not exceed $100.

Subjects were enrolled in our study and imaged using our NIR transillumination system in accordance with a protocol approved by the UC Irvine Institutional Review Board. Informed consent was obtained from all participating subjects, who were recruited among patients age 15 or older undergoing management of sinusitis or other similarly presenting diseases at the Otolaryngology-Head and Neck Surgery Clinic at the University of California at Irvine Medical Center. The sole inclusion criteria was that patients had undergone or were to undergo CT imaging, otherwise subjects were not discriminated on the basis of gender, ethnicity, or clinical findings.

NIR transillumination of the maxillary sinuses was performed in an examination room within the Otolaryngology-Head and Neck Surgery Clinic. Subjects were seated approximately 10 inches in front of the CCD camera that sat atop a tripod adjusted to the height of the patient. For hygiene purposes, the light source was covered with a sterile, disposable plastic bag that was discarded after each use. Patients placed the light source against their hard palates and were asked to cover their mouths with their hands to reduce backscattering of light directly into the camera. The room was then completely darkened, thus minimizing the amount of background signal. Images and videos of each patient's transillumination pattern were captured, archived on notebook PC, and were later compared to conventional CT images. Subjects were imaged from different perspectives in order to thoroughly examine each of their transillumination patterns.

RESULTS

A total of 17 patients were enrolled in our study and imaged using NIR transillumination. Of these, 5 had no evidence of maxillary sinus disease per CT scan and the remaining 12 had various degrees of disease, including various degrees of mucosal thickening to total opacification of one or both maxillary sinuses. Comparing NIR transillumination patterns with CT scans, we noted several trends.

Subjects without evidence of maxillary sinus disease per CT scan displayed diffusely strong transillumination patterns throughout regions of the mid-face, which includes the maxillary sinus (Figure 2). The optical signal was particularly strong in the region immediately below the eyes as NIR light penetrated through the maxillary sinuses and escaped back out via the infraorbital rims.

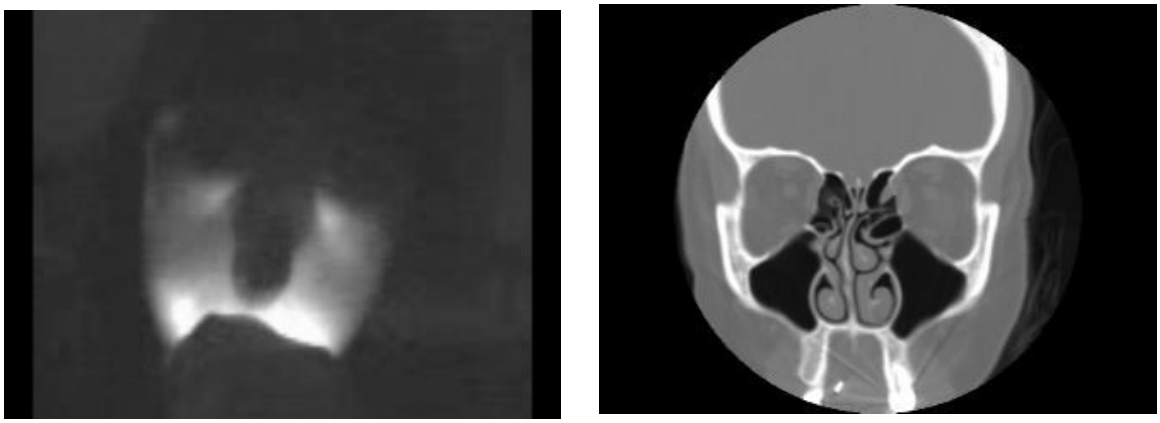

Figure 2. NIR transillumination pattern (left) of 33 year old Caucasian female with no history of nasal problems with corresponding CT scan (right) revealing bilaterally aerated maxillary sinuses. Note diffusely strong transillumination of mid-face structures with increased signal intensity along infraorbital rim.

Patients with extensive bilateral maxillary sinusitis, on the other hand, typically displayed relatively dim transillumination patterns (Figure 3). NIR light penetration through their maxillary sinuses was usually either diminished or absent. Of note, the strong optical signal immediately below the eyes that characterized disease-free patients was typically absent.

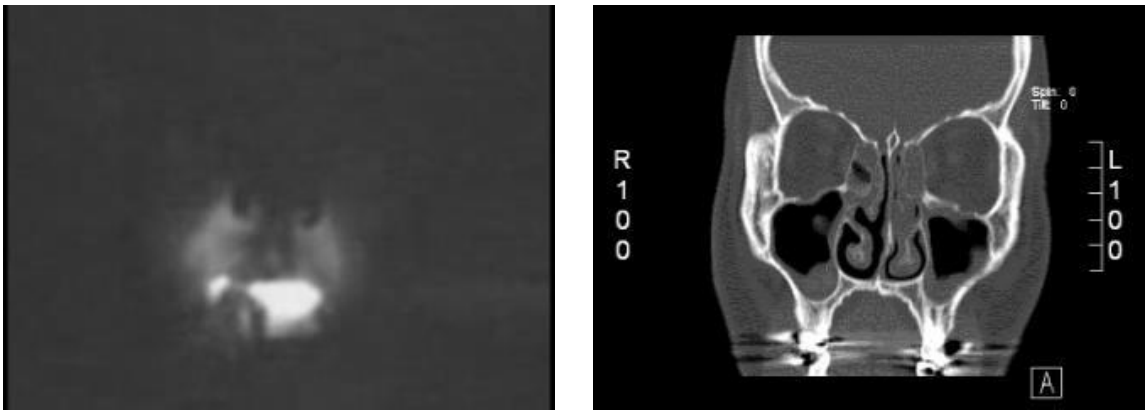

Figure 3. NIR transillumination pattern (left) of 54 year old Asian male with a diagnosis of chronic bilateral maxillary sinusitis with corresponding CT scan (right) revealing significant bilateral mucosal thickening of maxillary sinuses. Note relatively dim transillumination pattern with absence of light penetration into the maxillary sinuses.

In subjects that had extensive unilateral maxillary sinus disease, the transillumination patterns was notably asymmetrical, with diminished signal intensity on the affected side as compared to the unaffected side (Figure 4).

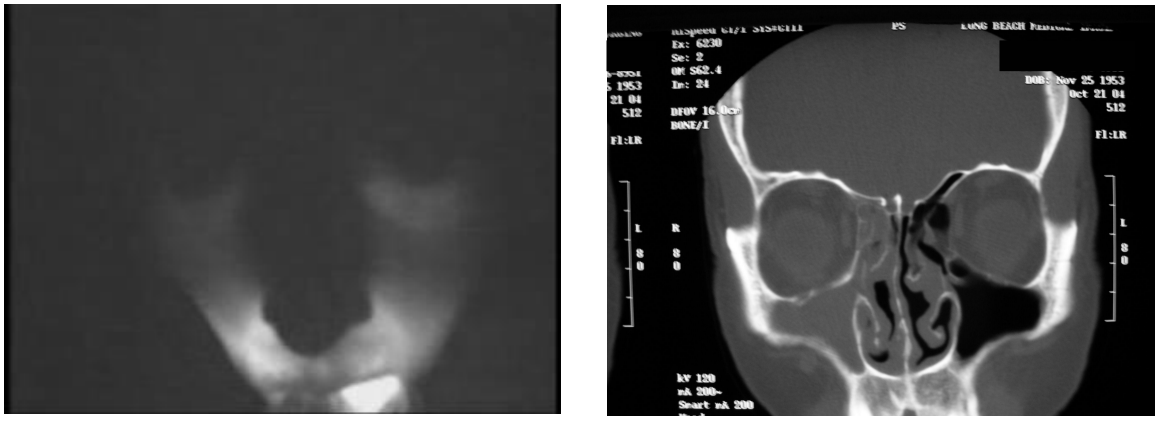

Figure 4. NIR transillumination pattern (left) of 51 year old Caucasian male with a diagnosis of unilateral maxillary sinusitis with corresponding CT scan (right) revealing total opacification of right maxillary sinus. Though subtle, note relatively dim transillumination pattern or right mid-face regions as compared to left, with particularly diminished light penetration through right infraorbital rim.

Finally, NIR transillumination was used to follow the subset of patients that underwent sinus surgery (n=2) for treatment of their sinusitis. Post-operative transillumination patterns revealed increased light penetration of the sinuses when compared to pre-operative imaging (Figure 5).

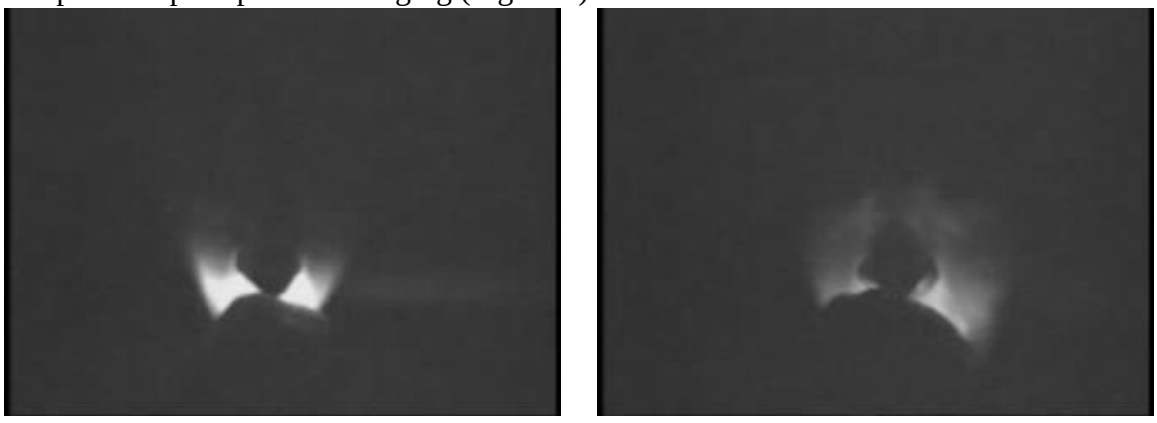

Figure 5. Pre-operative (left) and post-operative (right) transillumination patterns taken from 73 year-old Caucasian male who underwent surgery for chronic bilateral maxillary sinusitis. Note increased post-operative light penetration through maxillary sinuses.

DISCUSSION

The diagnosis of sinusitis has undergone constant evolution over the past century as imaging technology has improved. In the early part of this century, transillumination was the sole available imaging modality, however visualization of the sinuses was poor and the technique proved to be largely unreliable. With the advent of radiography, plain film x-rays became the standard diagnostic test and the diagnosis of sinusitis was improved. Today, CT has supplanted x-rays, providing detailed information regarding anatomy and tissue densities in the paranasal sinuses. While CT is excellent with respect to spatial resolution and definition of subtle tissue variations, its use in the management of sinusitis has been limited mainly to medical specialists to assist in planning surgical therapy or to evaluate for possible malignancy. Moreover, these studies are costly and involve ionizing radiation, and thus cannot be used serially to gauge the response to therapy. There is no simple, cheap, and safe method to accurately confirm the presence of sinus disease.

A possible solution to this problem is NIR transillumination. Our initial clinical studies using this technology indicate that air and fluid-filled maxillary sinuses could fairly reliably be distinguished by their differing NIR opacities. Our results show that normal, unilaterally diseased, and bilaterally diseased maxillary sinuses each display fairly characteristic patterns on NIR transillumination.

The advantages of NIR transillumination are multiple: it is safe for patients and, unlike CT or x-ray, does not utilize ionizing radiation; it is totally painless and only minimally invasive; it allows for real-time acquisition of results, which can be easily recorded and archived for future reference; it is inexpensive to manufacture and, moreover, can be made easily compatible with existing portable power sources already employed in primary care clinics (such as the Welch Allyn hand piece used widely for the otoscope and ophthalmoscope); lastly, as opposed to conventional transillumination, it can be performed in normal ambient light if used with the proper light filter.

A potential limitation of NIR transillumination, however, is that it is limited to the study of the maxillary sinuses and, potentially, the frontal sinuses; the sphenoid and ethmoid sinuses, which reside deeper in the skull, cannot be visualized using this technique. Nevertheless, the literature contends that the maxillary sinuses are the most commonly involved in sinus disease. This is because the maxillary sinuses are the largest of the sinus cavities and are probably the most frequently involved in sinus disorders due to their participation in the respiratory system (causing them to be subject to the same infectious and inflammatory processes) and close contact with the superior dental arch[14].

There are several potential applications for this technology. For the non-specialist practitioner, this technology would allow rapid and simple diagnostics of the paranasal maxillary or frontal sinuses without the cost or risk of standard radiography. This technology could be especially useful for the pediatric population, in which there is a great hesitancy to submit young children to radiographic studies. Furthermore, once a patient has been diagnosed with sinusitis, this technology could be a simple and safe means to follow the clinical response to medical or surgical therapy.

Clearly, much work needs to be done before NIR transillumination can make its way into the clinical setting. In terms of instrumentation, our future research goals include optimizing the use of wavelengths to get the most enhanced optical signal, to explore the use of imaging processing, and to make our device compatible with existing portable power sources and ambient light filters. In the long term, larger clinical trials will be needed to determine the sensitivity and specificity of this technique. Moreover, children will need to be included in future studies to determine the efficacy of NIR transillumination in this unique population. Finally, NIR transillumination may also be used to study the frontal sinuses, though these sinuses are of less import than the maxillary sinuses in terms of disease rates.

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